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Technical Guidelines for the Provision of Scientific Advice on the Precautionary Approach for Canadian Fish Stocks: Section 7 – Invertebrate Species

Lignes directrices techniques pour la prestation d'avis scientifiques dans le cadre de l'approche de précaution pour la gestion de stocks canadiens : section 7 – espèces invertébrées

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ABSTRACT

This report summarizes progress to date on the development of reference points for the management of various marine invertebrate species commercially harvested in Canada. The implementation of the precautionary approach (PA) to fisheries management in Canada requires the definition of reference points reflecting the productivity and reproductive capacity of a stock. The different invertebrate species commonly fished in Canada exhibit a very diverse range of life history characteristics. For these species, reproductive success will be a function of life history factors such as effective female fecundity, spawning opportunities for females, spatial patterns of age–size structure, the relationship between spawner density and fertilization success — especially for broadcast spawners with sedentary or sessile adults, spatial and temporal aspects of breeding areas, and the relationship between benthic settlement success and habitat suitability. For many species the time period between spawning and actually being able to observe recruits may be long enough so that cumulative environmental influences on survival could radically reduce year-class strength. Also, there is often a mismatch between managed areas and stock area so that recruitment success in one area may be affected by spawning success in another area. The lack of adequate models to account for these complexities has often resulted in the use of empirical methods to define the type of reference points expected by the DFO PA policy. To date, empirical methods have used either an estimate of or an indicator of population biomass or abundance to represent the productivity of the stock. Given that biomass alone is an incomplete measure of productivity, many invertebrate stock assessments rely on secondary indicators such as population size, composition-based and sex ratio-based growth changes, spawner abundance or biomass, abundance of prerecruits, predator abundance, environmental changes and spatial patterns of density, to modify stock status advice. For many sedentary species (e.g., bivalves and echinoderms), primarily spatially-based limits and targets for fisheries may be more appropriate. However, methods for spatial approaches still need to be developed.

RÉSUMÉ

Ce rapport résume les progrès réalisés dans le développement de points de référence pour la gestion d'une variété d'espèces d'invertébrés marins récoltés commercialement au Canada. La mise en œuvre de l'approche de précaution (AP) pour la gestion des pêches canadiennes nécessite la définition de points de référence reflétant la productivité et la capacité reproductive d'un stock. Les cycles de vie des différentes espèces d'invertébrés communément pêchées au Canada présentent des caractéristiques très diversifiées. Pour ces espèces, le succès reproducteur va dépendre de plusieurs de ces caractéristiques, tel que la fécondité réelle des femelles, les opportunités de ponte des femelles, les patrons spatiaux de distribution selon la taille et l'âge, la relation entre la densité de géniteurs et le succès de fécondation – particulièrement pour les espèces à fécondation externe dont les adultes sont sessiles ou sédentaires – les attributs spatiaux et temporels des aires de reproduction et la relation entre le succès de l'établissement benthique et la qualité de l'habitat. Pour plusieurs espèces, le délai entre le moment de la reproduction et celui où il est possible d'observer les recrues pourrait être assez long qu'il est possible que l'abondance d'une classe d'âge soit radicalement réduite par l'effet cumulatif de facteurs environnementaux affectant sa survie. De plus, il arrive souvent que les zones de gestion ne correspondent pas aux aires de distribution des stocks de sorte qu'il est possible que le recrutement dans une zone donnée soit affecté par le succès reproducteur d'une autre zone. En raison de l'absence de modèles adéquats pour tenir compte de toute cette complexité, on a souvent eu recours à l'utilisation de méthodes empiriques pour définir le type des points de référence requis selon la politique du MPO sur l'AP. Jusqu'à présent, les méthodes empiriques ont fait appel à des estimés ou indicateurs de la biomasse ou de l'abondance de la population pour représenter la productivité du stock. Étant donné que la biomasse est, à elle seule, une mesure incomplète de la productivité, plusieurs évaluations de stocks d'invertébrés modulent l'avis sur l'état d'un stock en fonction d'indicateurs secondaires tels que les variations de croissance reliées à la composition en taille ou au sex-ratio d'une population, l'abondance ou la biomasse des géniteurs, l'abondance des prérecrues, l'abondance des prédateurs, les changements environnementaux et les patrons spatiaux de la densité. Pour plusieurs espèces sédentaires (par ex. bivalves et échinodermes), il y aurait avantage à recourir à des cibles et des limites basées sur des critères spatiaux. Cependant, le développement de méthodes pour des approches spatiales reste encore à faire.

INTRODUCTION

The Department of Fisheries and Oceans' (DFO) implementation of the Precautionary Approach (PA) to fisheries management[1] requires the establishment of reference points linked to stock and ecosystem indicators. The policy states that these reference points will usually be determined using standard biomass and harvest metrics (e.g., fishing mortality or exploitation). In this case, reference points are to be defined for the biomass level below which reproductive capacity will be impaired (limit reference point or LRP), for the biomass level below which removals must be progressively reduced in order to avoid reaching the LRP (upper stock reference, USR) and for the maximum harvest rate expressed as fishing mortality or exploitation (removal reference). The recommended levels for the biomass reference points in the DFO policy are 40% and 80% of the biomass that results in the maximum sustainable yield (B_{MSY}). The removal reference must be less than that associated with the maximum sustainable yield (F_{MSY}). Estimates of B_{MSY} and F_{MSY} can be obtained from a number of population models generally used for the fish stock being assessed (e.g., surplus production, delay-difference, VPA/Adapt) along with models for the relationship between spawning stock size and the amount of recruitment from this spawning stock (commonly the Beverton-Holt spawner-recruit model). The setting of 40% B_{MSY} as the default LRP derives from research on threshold management strategies that rely on or are generalized from stock-recruitment relationships (e.g., Mace and Sissenwine 1993, Mace 1994, Punt et al. 2008).

The PA is, in general, about being cautious when scientific information is uncertain, unreliable or inadequate and not using the absence of adequate scientific information as a reason to postpone or fail to take action to avoid serious harm to the resource. The PA defines serious harm as negative impacts to the resource in the form of impaired productivity that would be serious or difficult to reverse[1]. A system has been harmed if it has lost resilience, meaning both the ability to recover from large perturbations and the ability to recover quickly from perturbations. Serious harm could be done to the species itself, to the ecosystem, and to the species component which is valued by society (e.g., for a fished species, that component that is harvested).

When MSY-based measures are not available then some other measure related to the productive potential and harvest should be used so that the objective of avoiding serious harm to the stock is realized. In the absence of a model, the policy recommends estimating B_{MSY} as either the average biomass (or index of biomass) over a productive period or the biomass corresponding to 50% of the maximum historical biomass.

In 2002, an international workshop on developing reference points for invertebrate fisheries was held in Halifax, Nova Scotia. The proceedings of the workshop were reported in Smith (2003) and seven keynote papers were published together in the August 2004 issue of the Canadian Journal of Fisheries and Aquatic Science. The introductory paper laid out the main issues with respect to invertebrate fisheries and reference points (Smith and Saint-Marie 2004).

> Invertebrates as a group comprise species with widely different life history characteristics and types of fisheries. Moreover, benthic invertebrate populations often exhibit complex spatial structure and are prosecuted by fisheries that afford the opportunity for passive or active high-grading by sex, size, or aesthetic criteria, and market incentives exist to encourage these practices. This may make invertebrate resources more susceptible than most marine fish species to spatially or quality-based serial depletions against which generic, dynamic pool model based reference points

[1] http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm.

offer little protection. Therefore, it is unlikely that many of the reference points being considered for fish species will be directly applicable to invertebrate species.

The workshop categorized invertebrate species commonly fished into life history groups mainly reflecting similarities in reproduction (e.g., broadcast, copulation), larval distribution (e.g., planktonic, brooding), mobility of adults (e.g., sedentary, mobile benthic) and types of fishery (e.g., spatial targeting, targeting of single sex). Discussion focussed on how to define the LRP in terms of recruitment overfishing within each of these life history groups.

Given the focus on recruitment, the workshop recommended that monitoring of reproduction capacity should be extended to aspects important in the mating systems such as local densities, spatial patterns of age or size structure, spatial and temporal patterns of breeding areas for broadcast spawners with poorly mobile or sessile adults, female size, male size, and the number of female reproductive opportunities for crustacean species with copulating adults. Current population models used to derive reference points do not incorporate these aspects. However, where available, estimates from these models may provide a starting point for determining management action, but empirical measures of stock condition were recommended as essential for groundtruthing the outcome of management actions and promoting timely reaction to unexpected changes in stock condition.

In this research document, the progress to date on methods for establishing reference points for invertebrate fisheries in Canada and worldwide is reviewed. The sources of information used reflect experience of the authors, information available through Canadian Science Advisory Secretariat (CSAS)[2] documents, scientific literature, other governments' sources and the Marine Stewardship Council (MSC) website[3].

MODEL-BASED REFERENCE POINTS

There appear to be very few invertebrate fisheries for which population models have been used for estimating reference points based on B_{MSY} (Table 1). The Northeast US scallop fishery is modelled using the CASA model (catch at size analysis) which uses size (shell height) instead of age from scallops in both commercial and survey catches (Sullivan et al. 1990, NEFSC 2010). Prior to 2010, reference points were estimated via yield-per-recruit proxies, i.e., F_{max} = F_{MSY} and B_{MSY}= biomass per recruit at F_{max} multiplied by median recruitment. Recent changes in selectivity towards large animals by the fishery have resulted in a flattening of the yield-per-recruit curves and F_{max} is no longer considered a proxy for F_{MSY} (NEFSC 2010). A new model, the stochastic yield model (SYM) was introduced in 2010 to estimate F_{MSY} and B_{MSY} directly (D. Hart, pers. com.).

In the remaining cases in Table 1, a Bayesian state-space version of the Schaeffer surplus production model (see Meyer and Millar 1999) has been used to estimate reference points. Corrections to the estimates of B_{MSY} and F_{MSY} accounting for process error did not seem to have been used or were not available when the original analysis was done (Bousquet et al. 2008). Bousquet et al. (2008) have demonstrated that deterministic estimates of these quantities are higher than when process error has been accounted for.

The posterior distributions for MSY estimates for green sea urchin were used to evaluate the probability of a range of catches exceeding MSY (DFO 2009a). Biomass is not regularly

[2] http://www.dfo-mpo.gc.ca/csas-sccs/index.htm.
[3] http://www.msc.org/track-a-fishery/certified.

monitored by surveys and the standard biomass and removal reference points were not used for this fishery.

The biomass and removal reference points for Scotian Shelf snow crab were derived for fishable biomass (FB) of mature males with carapace width greater than 95 mm (Choi and Zisserson 2012). They were accepted as first order-estimates that guide the formulation of equilibrium Harvest Control Rules. When FB > USR, a target removal reference of 10–30% of the FB is used based upon an examination of the biology of the species, past stock behaviour and discussions with industry. Secondary indicators of stock status are used to modulate the realised removal rate, as the stock assessment model does not incorporate important fluctuations in recruitment, size/age-structure, sex ratios, and environmental variability. When LRP < FB < USR, a target removal reference of 0–20% is used. When FB < LRP, closure of the fishery is recommended.

As for international examples, the seabob shrimp approach is similar to DFO policy but sets a more conservative LRP (Table 1). Few details were available in the MSC documents on the approach for the Baja red rock lobster.

EMPIRICAL REFERENCE POINTS

The DFO policy suggests a number of ways of using biomass estimates, survey estimates or other proxies when model-based estimates are not available. Most of the Canadian invertebrate fisheries that have defined or proposed reference points use a form of biomass proxy (Table 2).

MODEL ESTIMATES OF BIOMASS

The fisheries for sea scallops in the Maritime region are managed geographically as offshore fisheries (Georges, Browns, German, Sable, Western and Middle Banks) and inshore fisheries (Bay of Fundy and approaches, Scallop Fishing Area (SFA) 29 West). Total landings for 2011 were 5557 t and 1056 t, respectively. Many of the major components of these fisheries are modelled using a Bayesian state-space delay-difference population model (e.g., Smith et al. 2008, Hubley et al. 2011) to estimate population biomass, recruitment (to fishery) and exploitation rate, and to provide advice on future catch levels. Recruitment in the model comes directly from observations from annual stock surveys and not from a spawner/recruit model. The apparent lack of relationship between spawners and subsequent recruits in all of the areas suggests that recruitment success may be determined more by favourable environmental conditions than stock size for scallops (Smith and Rago 2004).

Estimates of surplus production for all of the modelled areas in both the inshore and offshore fisheries showed strikingly similar patterns (Figures 1 and 2; Smith and Hubley, 2012). That is, surplus production is highly variable over a range of stock sizes with no evidence of a definitive maximum, and low or even negative surplus production at the highest stock sizes. The highest stock sizes were due to the occasional large recruitment events experienced by all areas. The lack of a demonstrable stock/recruitment relationship and annual fluctuations in productivity are characteristic of most species of scallops (e.g., Orensanz et al. 2006).

The offshore scallop fishing industry proposed a precautionary approach framework in February 2011 to meet its first year conditions under MSC, using proxies for biomass-based reference

points for the most important fishing area, Georges 'A'[4]. Consistent with the DFO policy, the industry set B_{MSY} equal to the mean biomass (10,000 t, 1981 to 2009) from the delay-difference model. The USR was set at 8,000 t (80% of B_{MSY}) and 3000 t (30% of B_{MSY}) was used for the LRP. Note that 10,000 t approximately delineates the two periods of high and low average levels of biomass in this fishery. The choice of 30% of B_{MSY} for the LRP was not explained but this level does correspond to the biomass level for 50% MSY assuming the Schaeffer model for surplus production (NAFO 2004). By coincidence this level also corresponds to the lowest biomass observed in the 1981 to 2009 time series. The industry proposal also defined the mean exploitation of 0.25 as a removal target. This rate is very close to the 0.27 reported by Jonsen et al. (2009) as the exploitation rate that resulted in no change in biomass (E_{rep}, 1981 to 2007).

Currently, reference points based on the lowest biomass observed for the LRP and a proportion of the mean biomass (80% at present) as an USR, are being discussed with the inshore scallop industry. The target removal rate of 0.15 (exploitation), already established for the inshore fisheries will continue to be used. This rate corresponds to E_{rep} and was determined by comparing exploitation rates with subsequent biomass change and growth rates. The Full Bay scallop fleet has initiated a review for MSC certification in 2012 and reference points such as these are being considered.

For both inshore and offshore scallop fisheries, removal rates were set as targets not limits. This was done to allow for increased exploitation during periodic high recruitment events tempered of course by decreasing exploitation if biomass is indicated to drop below the USR.

Further work on density/spatially-based reference points has been part of the Maritimes ERI program and once completed could be used instead of or in addition to the above biomass-based reference points. In the meantime, the biomass-based reference points as described above are seen as a pragmatic way of managing to higher biomass levels.

Elsewhere in the world, various empirical approaches have been used or proposed for scallop stocks. There are currently three scallops stocks certified under MSC including Canadian offshore scallop, Patagonian scallop (Argentina) and Isle of Man Queen scallops.

A target reference point for the Patagonian scallop fishery[5] is defined in terms of the direct (total) biomass estimates made on all of the beds. That is, the fishery is only allowed to occur on those beds where more than 50% of the individuals are commercial size. The TAC set for the LRP corresponds to 40% of the "lowest" confidence limit of the biomass estimate.

The Isle of Man scallop fishery uses survey abundance indices for defining reference points and is discussed in the next section.

Model Estimates of Abundance

In the lobster fisheries on the coast of the northeast United States, current reference points are based on abundance estimates over a reference time period (ASFMC 2009, ASFMC 2010). The University of Maine model (Chen et al. 2005) generates the estimates of lobster abundance. From the 2010 Addendum (ASFMC 2010), the Gulf of Maine and Georges Bank stocks are

[4] http://www.msc.org/track-a-fishery/certified/north-west-atlantic/Eastern-Canada-offshore-scallop-fishery/assessment-downloads-1/26.07.2011_Offshore_Scallop_First_Annual_Surveillance_Report_Final.pdf.

[5] http://www.msc.org/track-a-fishery/certified/south-atlantic-indian-ocean/patagonian-scallop/assessment-downloads.

considered below the limit reference point (threshold), and overfished, if model abundance is less than the 25th percentile relative to the 1982–2003 reference period. Immediate action would be required if a stock were to fall below the 25th percentile. If the stock abundance is at or above the 75th percentile, a stock is considered in favourable condition.

BIOMASS ESTIMATES FROM SURVEYS

Northern Shrimp

In 2008, the Northern Shrimp (*Pandalus borealis*) resource within Shrimp Fishing Areas (SFAs) 5–7 (Figure 3) became the first Canadian fishery to become certified under the MSC; however, certification came with conditions that had to be met within specified timelines. Conditions under Principle Indicator 1 (Sustainability of Exploited Stock) required that:

(a) The informal precautionary reference points and decision rules currently guiding fishery management should be quantified and explicitly incorporated in the stock assessment and integrated fisheries management plan.

(b) Further work should be undertaken to develop and implement reference points based on stock biology, fishery characteristics and the limitations of the available data (Aschan et al., 2008).

To address these conditions, two National reference point workshops were convened in Ottawa, one during May and one during November of 2008 (DFO 2009b). Work completed to date and various potential reference points were discussed during the first meeting. Discussions also considered whether the shrimp off the eastern coast of Newfoundland should continue to be treated as individual stocks or should be treated as one large resource (meta-population) extending from Davis Strait south to the Northern Grand Banks. Potential reference points were presented to the fishing industry and various Non-Governmental Organizations during the second meeting. Using SFA 6 as an example, the period between 2001 and 2007 was treated as the productive period. The LRP and USR were respectively set at 40% (153,600 t) and 80% (307,300 t) of the geometric mean of the female Spawning Stock Biomass (SSB) over this time period (DFO 2009b). Since then, the large vessel industry has developed an alternative precautionary approach framework for SFA 6. They felt that the productive period should be between 1996 and 2003. The LRP and USR were respectively 30% (79,600 t) and 80% (212,300 t) of the geometric mean of the SSB over this time period. The fact that the productive period has been defined at two time periods highlights the problem with subjectively identifying the productive periods. As indicated in this example, there are obvious implications for setting reference points.

The industry version of the precautionary approach framework was adopted by DFO and can be found in the Annex I of the Integrated Fisheries Management Plan for Northern Shrimp[6] and is as follows:

- Total Allowable Catch (TAC) is set for two-year periods.
- Maximum 15% change in the TAC unless the stock is declining precipitously.
- If SSB ≥ 212,300 t, set the maximum exploitation rate = F_{MSY}.
- If SSB between 146,000 t and 212,300 t, set the maximum exploitation rate = 2/3 F_{MSY}, thought to be significantly above 15% of exploitable biomass.

[6] www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/ifmp-gmp/shrimp-crevette/shrimp-crevette-2007-eng.htm.

- If SSB between 113,000 t and 146,000 t, set the maximum exploitation rate = ½ F_{MSY}, thought to be above 15% of exploitable biomass.
- If SSB between 79,600 t and 113,000 t, set the maximum exploitation rate = 15%.
- If SSB is less than 79,600 t, set the maximum exploitation rate = 10%.

Unfortunately F_{MSY} has not been determined, but according to the above definition, if in the middle of the cautious zone ½ F_{MSY} is thought to be above 15% of exploitable biomass, F_{MSY} is assumed to be at least 30% of the fishable biomass in the healthy zone.

This framework has proven difficult to implement, therefore it is currently being revised.

Figure 4 depicts the SFA 6 harvest control rules as they presently stand. The exploitation rate in most years has been less than 15% and yet the resource within SFA 6 has been in decline since 2007. An additional problem is that fishing is allowed to continue within the critical zone.

Shrimp Fishing Area 7 straddles the 200 nmi limit within NAFO Division 3L and therefore is managed by the Northwest Atlantic Fisheries Organization. NAFO Scientific Council considers that the point at which a valid index of stock size has declined by 85% from the maximum observed index level provides a proxy for B_{lim} (19,330 t) for northern shrimp in Div. 3LNO (NAFO 2004). Currently, the female biomass index is estimated to be above but nearing B_{lim} (Figure 5). It is not possible to calculate a limit reference point for fishing mortality. A safe zone has not been determined in the precautionary approach for this stock.

A similar approach has been used for the Scotian Shelf shrimp (SFAs 14–16, Figure 6) based on the survey estimates of SSB, female exploitation rate and a suite of secondary indices (Figure 6, DFO 2010c, DFO 2011d, Hardie et al. 2011). The LRP and USR have been set to 30% (5,460 t) and 80% (14,558 t), respectively of the arithmetic mean of the survey estimates of SSB (18,198 t) during a productive period from 2000 to 2010. Although the 2011 stock currently remains in a productive period, the biomass reference points are based on data from 2000 to 2010 (rather than a constantly updated average) to avoid a scenario whereby redefined reference points based on a moving average would become less conservative in the event of a biomass downturn. The LRP is approximately equal to the average SSB during the low-productivity (pre-1990) period for this stock, characterized by low shrimp abundance, high groundfish abundance and relatively warm temperatures. The Scotian Shelf shrimp population previously increased from a low level during the transition from low- to high-productivity, so the working assumption is that shrimp could once again recover from this level given appropriate environmental conditions and fishing pressure (i.e., $B_{recover}$ proxy). Secondly, given the important role of shrimp in the Scotian Shelf ecosystem, particularly as prey for groundfish, this LRP is set to avoid a decrease in shrimp abundance below the level at which it was previously able to fulfill its ecosystem roles under a situation of high groundfish abundance (i.e., to avoid a scenario in which low shrimp abundance could act as a limiting factor in groundfish non-recovery). The USR has been selected at the default value. This was done to maintain a sufficient gap between the LRP and USR to account for uncertainty in the stock and removal reference values, and to provide sufficient time for biological changes in the population to be expressed, detected and acted upon.

The removal reference for Scotian Shelf shrimp is 20% female exploitation (actual female catch/SSB) when above the USR. This exploitation rate has rarely been exceeded during the modern fishery (2000–present), a period during which high commercial catch per unit effort (CPUE) and SSB have been maintained. Additionally, given that shrimp survive for approximately 3–4 years after their recruitment to the fishery, it can be approximated that on the order of 25–33% of the fishable biomass would be subject to natural mortality in any given year. As a result, the removal reference of 20% for shrimp is on the conservative side of this simplistic

estimation of natural mortality (25–33%). When the fishable biomass drops below the LRP, the fishery is closed. A suite of approximately 20 secondary indicators of shrimp abundance and production, fishing effects and environmental conditions provide a scientific interpretation of holistic data to inform the way in which science advises responding to the stock status and removal rate relative to reference points.

Snow Crab

In the case of the southern Gulf Snow Crab assessment, the LRP was set as the lowest survey biomass of hard shelled commercial-sized adult males (post-fishery estimated from the trawl survey) which produced good recruitment rates of Instar VIII (DFO 2010a). This value was estimated at 10,000 t (Figure 7, DFO 2012). In the absence of an explicit model, a provisional estimate of relative F_{MSY} for snow crab from the southern Gulf was taken as the average relative exploitation rate over the same period used to estimate B_{MSY} (DFO 2011b). A provisional estimate of B_{MSY} was taken as 50% of the maximum observed biomass over a productive period, 1997 to 2008 and estimated at 51,700 t (DFO 2012). The USR was set at 80% of the provisional estimate of B_{MSY}, i.e., 41,360 t. The estimate of F_{MSY} for snow crab from the southern Gulf was taken as the average exploitation rate over the same period used to estimate B_{MSY}. The F_{lim} value was calculated at 0.346, the average exploitation rate (harvest in year t divided by biomass in year t-1 estimated from the trawl survey) over the 1998 to 2009 fishery period.

In 2012 after the 2011 fishery and subsequent trawl survey, the polygon for biomass estimation was extended to cover the majority of snow crab habitat in the southern Gulf of St. Lawrence based on the recommendations at snow crab assessment workshop held in November 2011, and corresponding precautionary approach parameters were readjusted accordingly (DFO 2012).

The ratio of the catch to exploitable biomass can be inferred to be an estimate of absolute exploitation rate provided the survey catchability can be assumed to be 1.0. The ratio provides an index of exploitation rate that should be consistent from year to year provided catchability does not change over time. The method requires accurate monitoring of the commercial catch magnitude as well as regular survey estimates of the exploitable biomass. If the survey is based on a statistical design, then confidence intervals may be estimated for the survey biomass estimate. Typically confidence intervals do not exist for catch data and it is assumed that these data constitute a complete "census".

Arctic Surfclam

Reference points have been proposed for Grand Bank and Banquereau Arctic surfclam based on an estimate of fishable biomass from a single dredge survey in each area (Grand Bank: 2006, 2008 and 2009[7]; Banquereau: 2010). Dredge efficiency was estimated for Banquereau but assumed to be 1.0 for Grand Bank, which will result in an underestimate of current biomass. This bias will affect the average recruitment estimate at the same time, so the relative position of the current and target biomass estimates, and thus the determination of stock health, should be correct.

Using fishable biomass-per-recruit and estimated average recruitment, the B_{MSY} proxy would be 1,015,059 t for Banquereau and 703,065 t for Grand Bank. Since the stocks have never been depleted a stock-recruit function cannot be estimated nor can historic lows be used to estimate reference levels. Using the default 80% and 40% of the B_{MSY} proxy, the USR and LRP for

[7] Complete coverage of Grand Bank for surfclam took three years of survey work.

Banquereau are 812,047 t and 406,024 t. For Grand Bank they are 562,452 t and 281,226 t. A removal target of F = 0.33*M*[8] (Maximum Constant Yield, DFO 2007) has been recommended for Arctic surfclam (Banquereau, with similar approach for Grand Bank). Currently both stocks are in the healthy zone, above their target biomass and are being fished at a rate that is below the target removal rate.

This fishery is relatively new and has not had a high exploitation rate to date. The species is long-lived and there are a large number of year-classes in the catch. Because of this, it is not known how the stock or ecosystem would react to the stock being fished down to low levels.

SURVEY ABUNDANCE INDICES

The Isle of Man scallop fishery uses the slope and associated 95% confidence limits of a linear relationship between survey abundance and year as its MSC accepted reference level[9]. Current abundance estimates are compared with abundance in 2009, a year in which exploitation did not result in a decline in abundance. If the ratio of current abundance to that in 2009 is less than the lower confidence limit then the quota is proportionally decreased and if it is above the upper 95% limit the quota is increased. The increase may require evidence for a long-term trend to be implemented, such as strong recruitment in the near-term.

COMMERCIAL CATCH RATES

The primary indicator for scallops in SFA 20 (Magdalen Islands) is commercial catch rates from logbooks (DFO 2010b). Although there is a survey for this area, the fishermen were more supportive of using catch rate as the primary indicator, because of concerns about the survey (e.g., time of year). However, the catch rates for different size categories from the survey are used as secondary indicators. The temporal series for the catch rate from logbooks indicated decreases over three periods. The mean catch rate for the first period (1975–1984) was used to set the USR while the maximum of the period with the lowest catch rates (1997–2006) was used as the LRP. The fishery is actually managed by effort controls (days at sea) and both catch rate and landings have increased since 2008 aided by a strong recruitment event.

The commercial Spot Prawn (*Pandalus platyceros*, hereafter referred to as "prawn") trap fishery along the coast of British Columbia is managed using an escapement based model. Escapement is indexed using a Catch Per Unit Effort (CPUE, standardized by trap type and soak duration) of female spawners. Once total mortality (*Z*) drops the female catch rate index down to pre-determined levels commercial harvest is curtailed.

This escapement based system allows for maximizing annual catch (a commercial industry objective). Given the nature of the fishery it appears to be fully subscribed therefore it is reasonable to assume the exploitation rate on the spawning population is equivalent to the replacement or surplus production rate (minus *M*) at all biomass levels if fished down to a minimum escapement level. This minimum escapement is currently considered a provisional LRP in the context of the precautionary approach (DFO 2009b).

Determining the minimum escapement level or LRP for prawn stocks along the coast of British Columbia is a challenging undertaking. A LRP = avg. 1.7 females per standardized trap was arbitrarily set. Management adopted an arbitrary management target of LRP+10% at which

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[8] ***M*** **represents an estimate of natural mortality.**

[9] http://www.msc.org/track-a-fishery/certified/north-east-atlantic/Isle-of-Man-queen-scallop/assessment-downloads.

point no further commercial harvest takes place. This arbitrarily set LRP has been in place since 1979 and is still being used. Over the past 15 year time period prawn stock size (commercial catch is considered a reasonable proxy of abundance) has not shown any decreasing trend. Although the LRP has been arbitrarily set, which is not fully satisfying from a science perspective, it has proven to be sustainable through actual application.

A rudimentary reference point system based on catch rates has been used for scallop and prawn fisheries off of Queensland, Australia (O'Neill et al. 2005). These reference points have been derived from ad hoc methods and unstandardized catch and effort data. A limit reference point for saucer scallops was set at 70% of the average catch rate covering the period 1988 to 1997.

Many rock lobster fisheries in New Zealand and Australia use standardized commercial CPUE as a reference point or key indicator for decision rules (e.g., Breen et al. 2009, Linnane et al. 2011). The assessments for rock lobsters in New Zealand assume that trap CPUE is a valid index of abundance (Breen et al. 2009), and indices are based on the standardization of commercial CPUE. Decision rules vary by management unit, but generally involve comparison of the recent standardized CPUE to a target CPUE, sometimes with adjustment of the quota in direct proportion to the recent standardized CPUE. An Australian example of the use of CPUE for reference points is the Northern Zone Rock lobster fishery. Limit reference points for this fishery were set at the CPUE in 2004 when quotas were initiated; pre-recruit CPUE limit reference points are based on the mean during a reference period of 1995 to 2004 (Linnane et al. 2011). The pre-recruit index, developed from voluntary catch sampling since the 1990s, is the mean of the most recent three years.

COMBINED SURVEY BIOMASS AND COMMERCIAL CATCH RATES

Provisional reference points for shrimp fisheries in the Estuary and Gulf of St. Lawrence (EGSL: SFA 8, 9, 10, 12) were determined in 2008 based on female abundance (DFO 2009b). Recent work just completed has refined the approach. Since northern shrimp change sex, it was felt important to consider both males (recruitment to the female component) and females (spawning stock) in the stock status indicator. Stock status is now assessed through a combined index of survey data equally weighted with the fishery data restricted to summer (June, July and August) during which the catchability of males and females was assumed to be constant. The new reference points were determined from the best information available based on the stock status indicator series (1982–2010, DFO 2011c). The shrimp stocks increased from a relatively low abundance level in the mid-1980s and in the mid-1990s due to productive year-classes. Thus, it appears that the spawning stock was sufficient during these two periods to produce abundant cohorts which had a noticeable impact on stock condition. The stock status for these low abundance levels from which they have increased represents the LRP. The 1996 to 2002 period appears to represent a stable period during which catches proved to be sustainable. The average stock status for this productive and stable period represents an approximation of BMSY. The USR value, in compliance with the fishery decision-making framework for incorporating the precautionary approach, was proposed to be equal to 80% of this value.

Harvest guidelines for shrimp in the EGSL were established according to the stock status indicator and its position in relation to the stock status classification zones (healthy, cautious and critical). The observed relationship (1982–2010) between the stock status indicator of a given year and the harvest of the following year was used to build a harvest guideline with a constant removal rate in the healthy zone similar to the average of the exploitation rate observed between 1990 and 2010. The removal rate decreases in the cautious zone until it reaches a value that is one-quarter the rate in the healthy zone. These guidelines are compliant

with a precautionary approach and were used in the elaboration of decision rules to determine annual TAC.

An operating model which mimics the dynamics of the EGSL northern shrimp stock was used to make projections of the stock trajectory over 25 years (approximately four generations) under different scenarios. The operating model was based on a Leslie Matrix with realistic parameters and includes a sex change. A number of different hypotheses about the dynamics of the stock were included and different TAC decision rules were simulated. These models were used as a tool to determine the best rule amongst those being considered.

A series of workshops and consultations with industry, First Nations, provincial representatives and fisheries management were held to evaluate the performance of the reference points and harvest guidelines through the simulation studies. From these meetings, a precautionary approach including the proposed reference points, harvest guidelines and TAC decision rules was developed and accepted by all participants.

LANDINGS

The use of landings to define reference points has only been used for some lobster fisheries in Atlantic Canada. The lobster fishery takes place throughout Atlantic Canada, off the coasts of Newfoundland, Quebec, Prince Edward Island, New Brunswick and Nova Scotia. There are numerous Lobster Fishing Areas (LFAs), which are the units of management (Figure 8). The data discussed here comes from a well-studied LFA off the Magdalen Islands (LFA 22) and from some highly productive LFAs off the Atlantic coast of Nova Scotia and in the Bay of Fundy (LFAs 27–38).

Unlike many fish and invertebrate stocks, management of the lobster fishery is implemented through input controls that include a suite of measures to limit effort (e.g., closed seasons, limited number of licenses, trap limits), and to increase escapement (e.g., minimum and maximum legal sizes, size windows of protection, protection of females with eggs). In some LFAs there are also measures to control increase in fishing efficiency (daily fishing hours, hauls limited to one per day, trap size limits, maximum line length, a minimum number of traps per line). Only in the deepwater fishery off Nova Scotia (LFA 41) is there a quota in place.

For now, there are no working population models for Canadian lobster that provide estimates of biomass. The only way to have an indication of biomass levels is to use proxies. There is a working model for American lobster in the US (Chen et al. 2005, ASFMC 2009) and the application of this model to some lobster stocks in Atlantic Canada is under exploration[10]. For now and in the near term (at least 5 years for most LFAs) the use of landings as a biomass proxy is the best option for the lobster fisheries in LFA 22 and LFAs 27–38. Landings are the basis of candidate reference points in the Integrated Fishery Management Plan for Lobster Fishing Areas 27–38 (2011).

Given a number of assumptions (that can be considered reasonable in a number of LFAs) on fishing effort, fishing efficiency and catch reporting, the landings are assumed to be representative of the true lobster biomass. Available fishery independent data on abundance for some areas support this assumption. There are uncertainties and caveats in using landings as

[10] Tremblay, M.J. (editor). 2011. Proceedings of Workshop: Application of the University of Maine Lobster Stock Assessment Model to Canadian Lobster Stocks, Mar 8–10, 2011. Unpublished document provided to workshop participants and available from the editor.

pointed out by Tremblay et al. (2012) and Gendron and Savard (2012). These can be dealt with to some extent by reference to secondary indicators (such as demography, reproduction and recruitment), but ultimately alternatives to landings as a biomass proxy are needed. It is important to recognize that for a large number of LFAs, landings represent the only information available. A discussion on the gaps and uncertainties related to potential indicators and reference points for lobster was held during a national workshop on PA frameworks for input control fisheries (DFO 2010d).

DFO's PA Framework (Annex 1b[1]), suggests that reference points be based on the mean or median biomass at MSY (B_{MSY}) or a biomass proxy, such as landings over a productive period. For LFA 22 and LFAs 27–38, the 25 year period 1985–2009 was selected. This certainly represents a productive period, but for some LFAs also includes years when landings were substantially lower than at present.

For the USR and LRP, the values of 80% and 40% of the B_{MSY} proxy were used as suggested in the PA Framework. Where there were observations of lower landings in the 1985–2009 period from which the fishery recovered, these values were used as the LRP. The LRP was always well above the lowest landings observed from 1947–2009 in LFAs 27–38. In LFA 22, the LRP was set at 40% of the B_{MSY} proxy which coincides with the low levels of landings observed at the beginning of the 1970s, after which a three-fold increase in landings was seen in the following 20 years. It is assumed that the LRP corresponds to a point from which the stock would presumably be able to recover, given environmental conditions remain favourable. The stock is currently considered to be more robust than in the past because of the much higher minimum legal size which affords a better reproductive capacity.

When the biomass indicator drops below the USR, it indicates that the current biomass cannot support the current exploitation rate and some action must be taken. Exploitation should not exceed replacement rate. In the context of an input-managed fishery (no quotas), actions could include increasing escapement through technical measures, or reduced exploitation by reducing the number of trap hauls. In LFA 22, control rules were predetermined for each zone of the stock status (healthy, cautious and critical) and agreed upon by the industry. Successive and additive measures of escapement and effort control have been predetermined if stock falls in the cautious zone. Partial closure of the fishery will be imposed if stock falls in the critical zone at a level decided by a recovery committee.

The recent (last 25 years) fishing history has shown, empirically, that at the present levels of biomass, the level of exploitation has been sustainable in most LFAs. At least two generations of lobsters have been produced in high numbers, demonstrating the ability of the stock to renew itself. It also indicates that the current rate of exploitation is below or equal to the level of replacement, or surplus production. Under the current fishing scheme and biomass level, the risk of collapse of the stock is acceptably small. Current levels of exploitation are known to be high in lobsters (50–90% of harvestable sizes). However, the series of escapement measures currently in place (protection of berried females, minimum legal size > size at sexual maturity in many LFAs, efficient gear selectivity) provide the basis for the sustainability and robustness to high exploitation rates.

Although sustainable, the catch may not be maximized at the current levels of exploitation. Yield-per-recruit calculations have shown in the past that long-term yields could theoretically be increased with a reduction of fishing mortality. Further work including density-dependant effects would be needed to better understand how catch yields could be maximized.

Developing a precautionary approach for lobster based on the recent history of the fishery has to account for the current highly productive regime. As such, reference points developed at

present will be relevant only for this set of conditions. If there is a significant shift in the regime, redefinition of reference points will have to be considered.

FUTURE PLANS

CRABS

Dungeness Crab

The commercial Dungeness crab fishery on the Fraser River Delta, British Columbia, is currently managed with a minimum size limit (165 mm carapace width point-to-point), non-retention of females, and a restricted fishing season (June to November) to protect large males during the winter/spring moult period. There is no restriction on the fishing mortality rate for legal-sized males. Thus, fishing mortality may not be a good candidate for establishing biological reference points. Instead a surrogate for population abundance, catch rates from standardized fishery-independent trap surveys, is used. Fishing gear was standardized by ensuring trap type, bait type and quantity, and soak time remained consistent.

An alternative approach based on stock-recruitment relationships has been investigated. Variations in legal male, female, and sublegal male Dungeness crab abundance were evaluated at the beginning and end of each fishing season using trap surveys from 1988 to 2010. Proportions of different crab types and soft-shell crabs in commercial catches were also examined. A good relationship was found between female abundance and corresponding legal male abundance five years later, which was well described by the Beverton-Holt stock-recruitment model.

For a compensatory stock-recruitment relationship such as the Beverton-Holt model, recruitment rate or per capita production should increase when population size decreases as density-dependent mortality decreases. In reality, however, recruitment may not rebound when population biomass has fallen to a certain low level. Examples include the red king crab (*Paralithodes camtschaticus*) fishery near Kodiak Island, Alaska, and the blue swimmer crab (*Portunus pelagicus*) fishery in Cockburn Sound, Australia. Populations may fail to recover from low abundance levels because of ecological interactions.

The Dungeness crab population was assumed to stabilize at the existing abundance when fishing is suspended in situations where the stock has shown signs of steady declines. Namely, continual fishing on the decreasing population will further reduce the population size. The established stock-recruitment function together with information on crab trap catch proportions was used to assess the amount of potential reduction in female and legal crab abundance before the population reaches another lower equilibrium, if fishing persists. When potential reduction is small and the population size is large, current fishing practices may continue. When potential reduction is large and the population size is small, management measures must be taken to safeguard the resource.

A simulation study showed the impact of fishing at the current intensity on the crab population depends on crab population size relative to maximum recruitment, as indicated by the parameter α in the Beverton-Holt stock-recruitment model. The amount of reduction to legal male and female crabs increased with decreasing population size. The amount of reduction was relatively low when legal crab abundance was greater than 50% of the maximum possible recruitment; the amount of reduction was much higher when legal crab abundance was approximately 20% of the maximum recruitment. From this work is was proposed that the two female abundance levels corresponding to legal crab abundance levels at 50% and 20% of

maximum recruitment from the stock-recruitment model could be used as the USR and LRP, respectively, for managing the Fraser River commercial Dungeness crab fishery according to the Precautionary Approach.

Snow Crab-Newfoundland

Depletion of the residual biomass at high exploitation rates is associated with increased capture, handling, and mortality of released soft-shelled immediate pre-recruits. Long-term yield may be maximized and sustainability approached (if not fully realized) by minimizing this mortality, thereby maximizing recruitment. Future work could look at how this might be achieved by maintaining some minimum proportion of the residual component (versus recruitment) within the exploitable biomass.

Snow Crab-Quebec

Snow crab populations in most Quebec fishing zones appear to exhibit quasi-cyclic fluctuations in abundance. Into and during a recruitment crest the biomass of legal males may increase or remain stable even with very high catches (exploitation rates), whereas into and during a recruitment trough the biomass of legal males will decline whatever the catch (or exploitation rate). Thus, the challenge is to adjust catches (or exploitation rate) through a recruitment pulse to levels that will not impair formation of a recruitment pulse of similar amplitude and period to the previous. This is a desirable outcome under the assumption that the biomass of large terminal moult males is not the driver of population oscillations and not an impediment to population "stability" (re: some industry stakeholders have argued that populations would oscillate less if large males were fished heavily).

Maintaining a constant exploitation rate may not be desirable, since in fished populations peak abundance of first-time breeding females (primipara) usually coincides with minimum or near-minimum abundance of legal-terminal moult males. One might consider that exploitation rate should be relaxed during recruitment troughs starting when the biomass of legal-terminal moult males begins to decline. Although only males are fished, and recommendations for catch and exploitation rate are relative to male biomass, reference points based on a mixed indicator of female and male spawning biomass are probably desirable. The challenge remains of including an assessment of effective female fecundity (to counter possibility of sperm limitation) into setting reference points.

Snow Crab-Southern Gulf

The PA objective of avoiding serious harm includes avoiding the loss of a phenotype (e.g., large size at maturity for male crab) for a sustained period of time (e.g., one or more generations). In the case of snow crab, the large size at maturity for male crab has evolved as a life history strategy. Size-at-adulthood is considered to be at least in part heritable in snow crab because sexual size dimorphism favouring males is particularly well developed in this species and is usually the product of sexual selection, one of the strongest and most rapid-acting evolutionary forces (Shuster and Wade 2003). The environment, particularly temperature, cannot be controlled and it can play a synergistic or antagonistic role to fishing, by increasing or reducing the male population component that becomes vulnerable to fishing (through a change in size-at-adulthood) and the spatial scales for density-dependent processes (through habitat contraction or expansion).

The current approach and recommendations for exploitation rate are uniquely relative to male biomass. Establishment of reference points based on an interaction between female and male spawning populations are desirable. For fisheries like snow crab that target a specific sex, sex

ratios should be a consideration in reference point definitions (Orensanz et al. 1998). It has been suggested that reference points in invertebrate species could also be based on setting a minimum abundance of spawners to take advantage of favourable environmental conditions, or maintaining a minimum density of mature animals in an area to ensure successful fertilization, or the establishment of refugia have been proposed for exploited marine crab species (Orensanz et al. 1998, Smith 2003).

The lack of a demonstrated stock and recruitment relationship, the extent of density dependent effects across cohorts, and the role of environmental variability in modifying growth and survival for snow crab are the major sources of uncertainty presently limiting the development of reference points not based on proxy methods. These interim reference points are specific to the snow crab biological unit from the southern Gulf and should be re-examined and revised as new information is obtained.

LOBSTERS

For all LFAs, alternatives to landings as the sole commercial biomass proxy are needed. Where the alternative is not fishery-independent, protocols should be developed to conduct periodic fishery-independent surveys for application if the biomass proxy approaches the cautious zone. Secondary indicators will be important for both evaluating stock status and informing the type of management response to a stock that has entered the cautious zone.

The University of Maine model will be explored for application to one or more lobster assessment units.

In Newfoundland, landings, under various assumptions, will be used as a proxy for biomass as in other Atlantic Canada Regions. In all four sub-regions in Newfoundland (North-east, Avalon, South Coast and West Coast) landings increased in the mid-seventies after the implementation of a limited-entry licensing policy and regulations on trap numbers (Figure 9). These landings were sustained until the early 1990s in three sub-regions and continued to increase on the south Coast until 2010. There are no estimates of exploitation rates during this time period. After 1993, three out of four sub-regions went into decline. Under this scenario the sustainable levels of catch for lobster from Newfoundland waters cannot be determined.

Given the difficulty in determining sustainable levels of biomass, attention could be better focussed on the level of biomass for the LRP. One such candidate for a B_{lim} would be the lowest observed biomass (B_{loss}) from which there had been a recovery. At this level there is a high risk of serious or irreversible harm. Other criteria can be used to set the USR point to meet the criteria for the Precautionary Approach. However determining these criteria will need further investigations.

As an example of a B_{lim}, the mid-1970s landings levels in each of the four sub-regions in Newfoundland and Labrador could be used as limits:

Sub-Region	Landings (t)
North-east Coast	210
Avalon	90
South Coast	350
West Coast	375

Both North-east Coast and the Avalon sub-regions are already at this B_{lim}.

SCALLOPS

Models have not been developed for SPA 5 (Annapolis Basin) and 6 (Grand Manan), and stock assessments are primarily based on commercial catch rates in addition to survey trends for the latter area. For the modelled areas, catch rates are highly correlated with biomass (and survey) estimates and it may be possible set LRPs and USRs based on the catch rate series (e.g., DFO 2010c). Discussions with the industry and fisheries management will be needed on this option.

For scallop fisheries in other areas of the world (e.g., Australia, Ireland, UK), spatially structured reference points, closed areas or rotational areas fishing plans are being discussed (AFMA 2007, Harrington et al. 2007, Smith 2008, Tully et al. 2007). Target reference points are not defined for the Australian Bass Strait Commercial scallop fishery but a B_{Lim} proxy of one viable area containing at least 500 t estimated biomass has been implemented (J. Harrington, UTAS, pers. com.).

The SFA 29 West area has been the focus of spatial and habitat research following the completion of the joint Industry, Natural Resources Canada and Department of Fisheries and Oceans multibeam project in 2005 (DFO 2006, Smith et al. 2009, Tremblay et al. 2009, Todd et al. 2012). Recent work as part of the Maritimes Region Ecosystem Research Initiative program has concentrated on identifying scallop habitat based on metrics derived from the multibeam bathymetry and backscatter and image surveys (Brown et al. 2012). Comparison of the spatial patterns of fishing intensity based on Vessel Monitoring System (VMS) data with scallop habitat suitability indicates a strong positive relationship. A similar strong relationship is evident for annual survey catch per tow of commercial size scallops with scallop habitat suitability. Trends of densities (ton/m^2) for survey biomass estimates and catch data by low, medium and high scallop habitat suitability indicates that the highest densities for both occur initially in the higher suitability areas and fishing tends to level out the densities over all areas. The trend of increasing decline in densities from the higher suitability areas follows the predications of the stages of the spatial impact of a fishery on a population given in Caddy (1998) with the condition of similar densities everywhere corresponding to his third stage. The fourth and final stage corresponds to fishing out of key areas, with continuing declines in commercial catch rate. The observed trend in decreasing densities as a function of habitat also follows that predicted by basin model for a sedentary species (MacCall 1990). Current work is concentrating on using a combination of productivity, density and area to identify a set of LRPs and USRs that could be used for the scallops in this area and eventually the other areas being managed.

SHRIMP

Northern Shrimp-Newfoundland

There are no harvest control rules associated with the NAFO precautionary approach for the Northern Shrimp fishery within NAFO division 3L and TACs are set on an "ad hoc" basis. As in the SFA 6 case, exploitation rates over the period 2006–2009 have been near 15% and have been followed by stock decline. Once again this is evidence that exploitation rates should be at or below 15%.

Fisheries Commission has requested advice on the identification of F_{MSY}, B_{MSY} and advice on the appropriate selection of an USR for biomass within SFA 7. Bayesian (Hvingel and Kingsley, 2002) and maximum likelihood methods (P. Shelton, pers. com.) have been used to fit surplus production models. It is hoped that the Bayesian model will be further refined and presented in

2012 as a potential assessment model for the stock. As an alternative, An Index Method (AIM)[11] is being applied to the data in an exploratory analysis to estimate the replacement exploitation rate which can be used as a proxy for F_{MSY}.

Until formal models have been accepted, caution should be exercised in setting TACs because water temperatures have been warming over the past decade. Effects of a warm regime on shrimp distribution and behaviour are unknown. However, a warm surface regime is believed to be detrimental to shrimp early survival and subsequent recruitment (Aschan and Ingvaldsen 2009, Koeller et al. 2009, Richards et al. 2008). Additionally, shrimp and capelin are key forage species in NAFO Divisions 2J3KL (SFAs 5, 6 and 7). Capelin abundance is at very low levels while some groundfish are increasing. The opposition of these two trends may increase predation pressure on shrimp.

Spot Prawn

A subsequent study of spot prawn in one small area of the British Columbia coast identified a stock recruitment relationship and an estimated Spawner MSY (S_{MSY}) to be approximately 3.4. (Boutillier and Bond 2001). These results combined with recent work in developing an operating model for Management Strategy Evaluation may prove useful in determining, through simulations, an escapement level tipping point (point on the stock/recruitment replacement line) where the surplus production realized is insufficient or too small to support a sustainable harvest at a commercial fishery scale if fished to maximum sustainable catch. If in fact this can be achieved, it would be sufficient grounds for establishing an empirically derived LRP. This is akin to discussion in Caddy and Mahon (1995) on determining an F corresponding to the point on the S/R curve that will likely result in stock declines (F_{high}). If uncertainty is not accounted for in determining F_{high} then a more conservative F would have to be selected. In the case of prawns determining a value for F is at this point very challenging so the empirical route for setting an LRP is currently being pursued.

[11] http://nft.nefsc.noaa.gov/AIM.html.

DISCUSSION

Model-based reference points are rarely available for invertebrate fisheries possibly due to the lack of appropriate data or the lack of evidence for stock/recruitment relationships or both of these reasons. While the former case might be mitigated through investment in additional monitoring programs, the latter may be a consequence of the "important aspects in the mating systems" raised in the Invertebrate workshop (Smith 2003, Smith and Sainte-Marie 2004). If the indicator for stock status is defined as some population quantity that management measures can directly affect but is not something directly associated with reproductive success (e.g., male only fishery for snow crab) then it may be difficult to construct a model that will provide the requisite reference points.

Further, with the possible exception of the US scallop stochastic yield model, the other models that have been used do not explicitly estimate the steepness parameter of the implied stock recruitment relationship and this parameter can have a large effect on the appropriate proportion of B_{MSY} to B_0 when a Beverton-Holt model is used (Punt et al. 2008). Note that a Schaeffer model assumes 0.5 for the ratio of B_{MSY} to B_0. Hilborn and Stokes (2010) point out that previous work by Myers et al. (1999) reported that the distribution of estimates of the steepness parameter from a meta-analysis of species within three major taxa of marine fish indicated midpoints ranging between 0.7 and 0.8. Punt et al. (2008) show that steepness parameter estimates in that range, correspond to ratios of B_{MSY} to B_0 of 0.25 to 0.30 for a Beverton-Holt model. Therefore simply assuming $B_{MSY} = 0.5\ B_0$ could result in setting reference points that do not reflect the maximum productivity of the stock.

Empirically-based reference points are more common for invertebrate stocks in Canada and elsewhere in the world. Hilborn and Stokes (2010) argue in general for empirically-based reference points that reflect the known history of the stock and avoid defining B_{MSY} and B_0, as well as avoiding issues with respect to the (usually unknown) steepness parameter. While biomass or biomass-proxy based empirical reference points may not adequately reflect the complexities of the reproductive dynamics of the species, in some cases they could reflect at an aggregate level, the range of productivity observed to date. If this range of productivity can be coupled with an estimable history of actual or relative exploitation, then these reference points may offer management options for maintaining mid to high levels of biomass. Setting the LRP to the lowest observed biomass (or proxy) or some percentage of the mean biomass over the series may not necessarily reflect the capacity of the stock to recover at low stock size. However, the LRP probably represents a biomass level that would have severe economic repercussions for the fishing industry that they would be willing to avoid. While it may not be possible to set an empirical USR or target in relation to maximum productivity, the level should be high enough to allow management measures time to avoid having the biomass decline anywhere near the LRP.

Secondary indicators of productivity are important in current assessment of many invertebrate stocks and it is proposed that these be used in management decisions in addition to biomass-based stock status indicators. These include such things as current environmental conditions, predator abundance, recruitment indices, growth changes associated with size composition and sex ratios. There is at present no particular framework for including these indicators into decision rules but given that in many cases biomass may only partly reflect the productive capacity of a stock, these indicators could become very important in application.

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Table 1. Invertebrate fisheries where population models used to estimate B_{MSY} for establishing reference points.

Common name	Location	LRP	USR	TRP	Removal	Indicator	Source
Scallop	US Northeast	0.5 B_{MSY}		B_{MSY}	F_{MSY}	Stochastic Yield Model	NEFSC 2010, D. Hart, pers. com.
Green Sea Urchin	British Columbia	MSY		Prob(Catch >MSY)	F_{MSY}	CPUE & survey	DFO 2009a
Snow Crab	Scotian Shelf	$B_0/4$	$B_0/2$		F_{MSY}	Survey	DFO 2011a
Seabob Shrimp	Suriname	B/B_{MSY} =0.60		B/B_{MSY} =1.10	F/F_{MSY} =1.0	CPUE	MSC[12]
Red rock lobster	Baja	NA		$B_0/2$	NA	NA	MSC[13]

Note: Lower reference points (LRP), Upper stock reference (USR), Target reference points (TRP).

[12] http://www.msc.org/track-a-fishery/certified/western-central-atlantic/suriname_atlantic_seabob_shrimp.
[13] http://www.msc.org/track-a-fishery/certified/pacific/mexico-baja-california-red-rock-lobster.

Table 2. Invertebrate fisheries where a biomass proxy has been used to estimate reference points.

Common name	Location	LRP	USR	Removal	Indicator	Source
Scallop	Georges Bank	0.30 Mean	0.8 Mean	0.25, target	Model Biomass estimates	MSC[14]
Scallop	Bay of Fundy	B_{rec}	0.80 Mean	0.15, target	Model Biomass estimates	Smith and Hubley 2012
Scallop	Magdalen	max of 1997-2006	Mean of 1975 to1984	NA	CPUE	DFO 2010c
Shrimp	Scotian Shelf	0.30	0.80	0.20, limit	Survey Female SSB	DFO 2009b
Shrimp	SFA 8, 9, 10, 12	$I_{recover}$ (lows of mid-80's, 90's)	0.8 of mean I (1996 to 2002)		I = combined fishery and survey index	DFO 2011c
Shrimp	SFA 2-6	0.30	0.80	0.15, limit	mean survey SSB for 1996-2003	DFO 2009b
Pink and sidestripe shrimp	BC	0.40	0.80	0.35, limit	Ln(mean survey biomass)	DFO 2009b
Spot Prawn	BC	avg. 1.7 females per std trap + 10%		NA	standardized trap survey	DFO 2009b
Snow Crab	southern Gulf	$B_{recover}$	0.80	Mean $Catch_t / B_{t-1}$	0.5 max Survey biomass 1997-2008	DFO 2011b
Snow crab	Kyoto	0.33 max	0.66 max	F_{lim}? But not defined	Survey maximum biomass	MSC[15]
Lobster	Scotian Shelf	0.4 of median	0.8 of median	NA	Median of Landings 1985–2009	Tremblay et al. 2012
Lobster	Magdalen	0.4 of median	0.8 of median	NA	Median of Landings 1985–2009	Gendron and Savard 2012
Lobster	Gulf of Maine & Georges Bank	25th percentile	75th percentile	NA	Model abundance of sizes >78 mm CL, 1982–2003	ASFMC 2010

[14] http://www.msc.org/track-a-fishery/certified/north-west-atlantic/Eastern-Canada-offshore-scallop-fishery/assessment-downloads-1/26.07.2011_Offshore_Scallop_First_Annual_Surveillance_Report_Final.pdf.

[15] http://www.msc.org/track-a-fishery/certified/pacific/kyoto-danish-seine-fishery-federation-snow-crab-and-flathead-flounder.

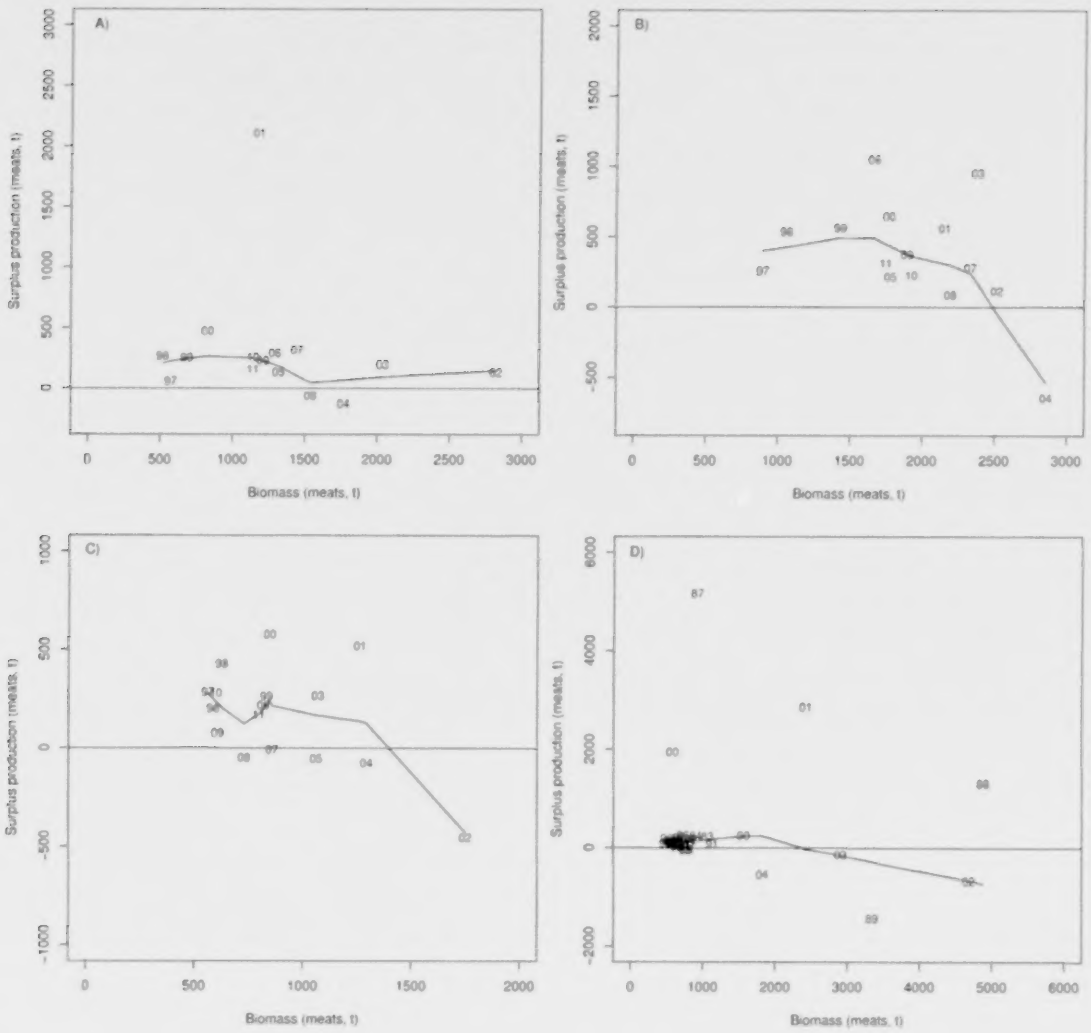

Figure 1. Surplus production for Bay of Fundy scallop fishing areas A) SPA 1A, B) SPA 1B, C) SPA 3, D) SPA 4. Labels refer to year of the survey and biomass was estimated by the delay-difference model. Loess curve added to detect trend.

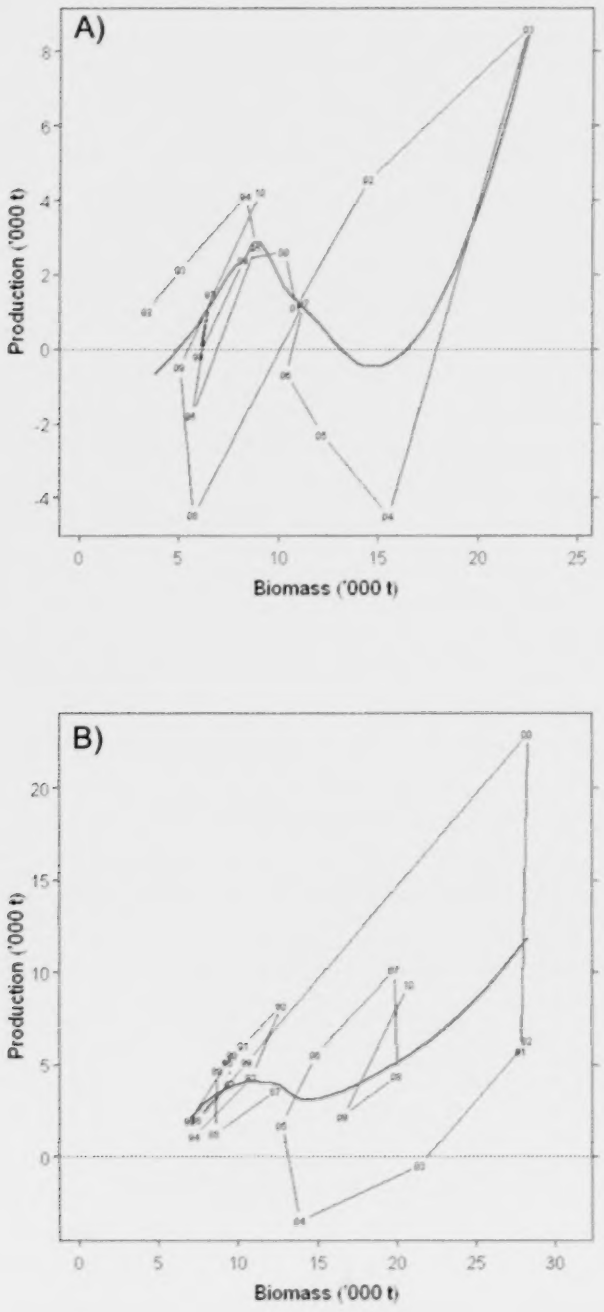

Figure 2. Surplus production for scallops on A) Browns and B) Georges Bank. Labels refer to year of the survey and biomass was estimated by the delay-difference model. Loess curve added to detect trend.

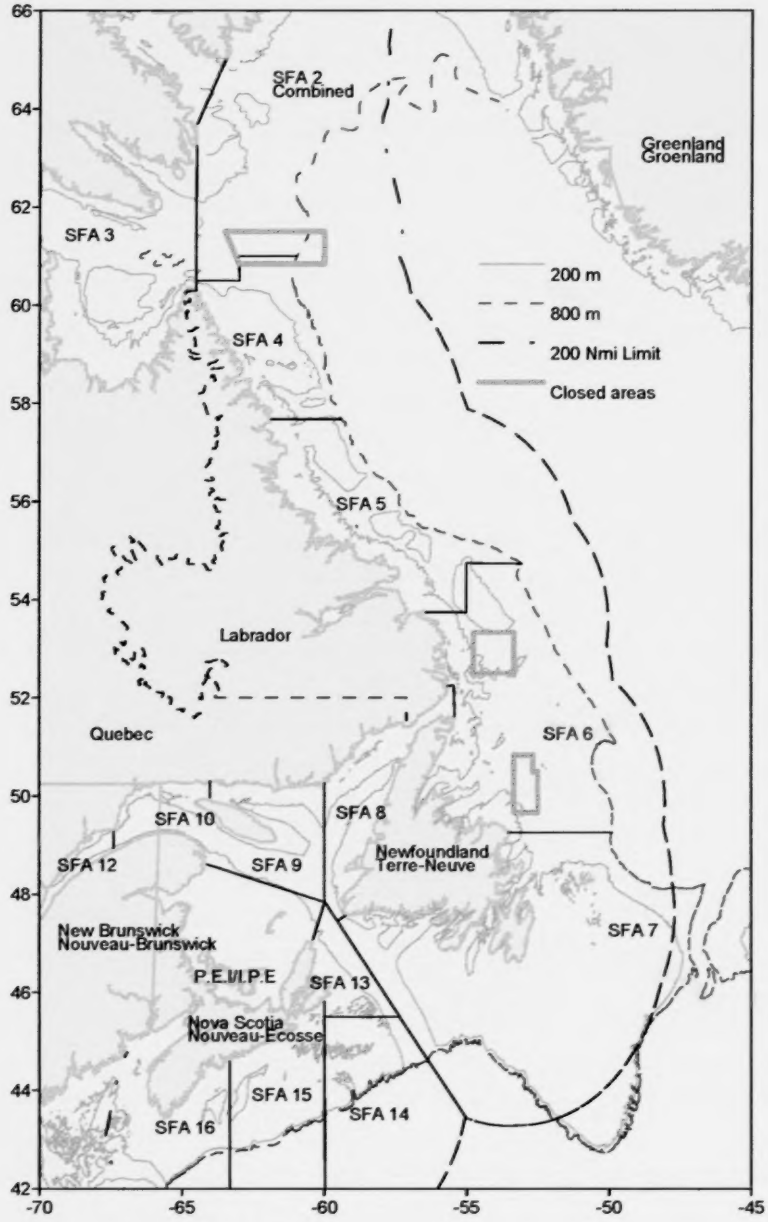

Figure 3. Northern Shrimp fishing areas 2–16.

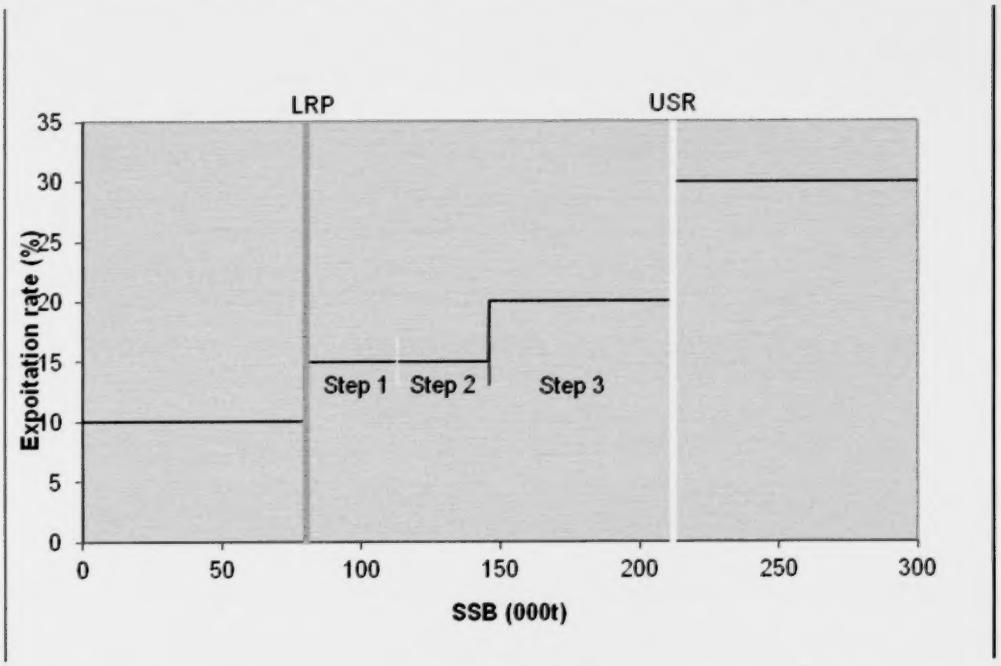

Figure 4. The SFA 6 harvest controls rules for Northern Shrimp.

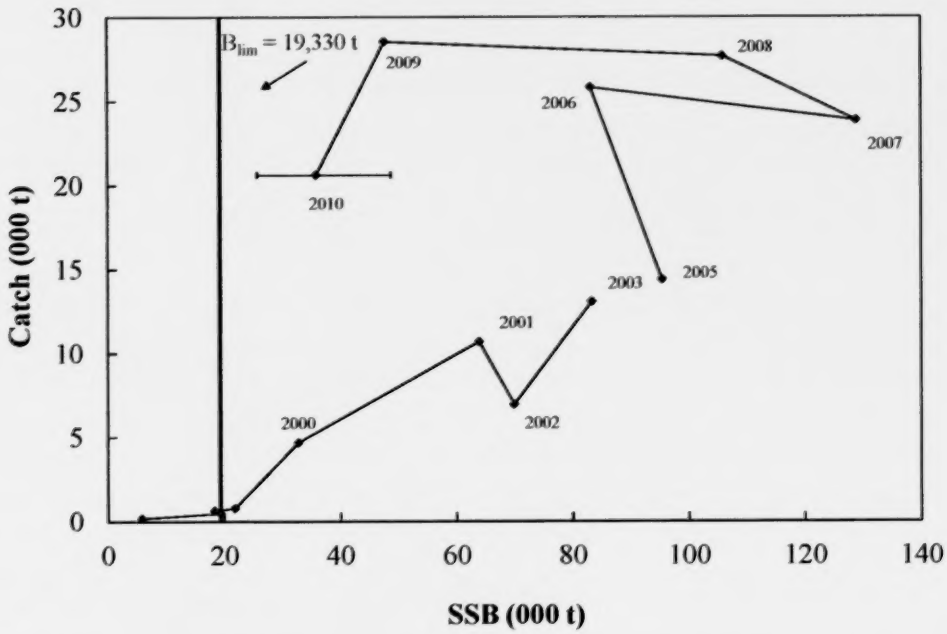

Figure 5. Catch against female biomass index from Canadian autumn survey for Shrimp Fishing Area 7. Line denoting Blim (approximately 19,000 t) is drawn where female biomass is 85% lower than the maximum point in 2007. The bar on the 2010 data point indicates the 95% confidence limit.

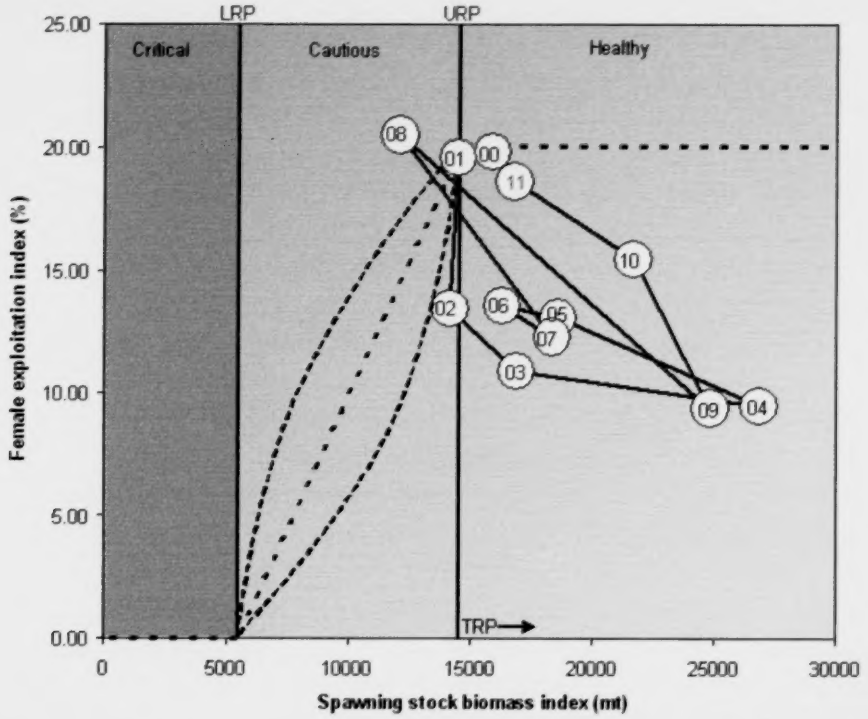

Figure 6. Graphical representation of the precautionary approach for Scotian Shelf shrimp. The dotted lines in the cautious zone represent a range of management actions possible, depending on whether the stock is stable, increasing or decreasing, or on trends in other indicators of stock or ecosystem health.

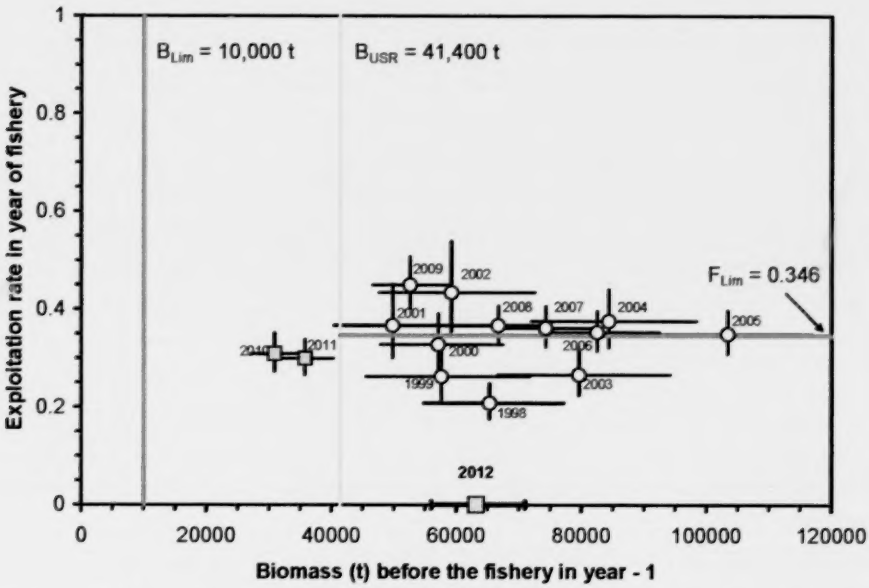

Figure 7. Trajectory of the southern Gulf of St. Lawrence snow crab stock along the stock status axis (biomass of snow crab (t)) and the exploitation rate axis (catch / biomass) for the 1997 to 2008 survey years. Year of the fishery is labelled on the figure. Error bars are 95% confidence interval ranges. Biomass and exploitation rate levels labelled with open circles were used to define the reference points.

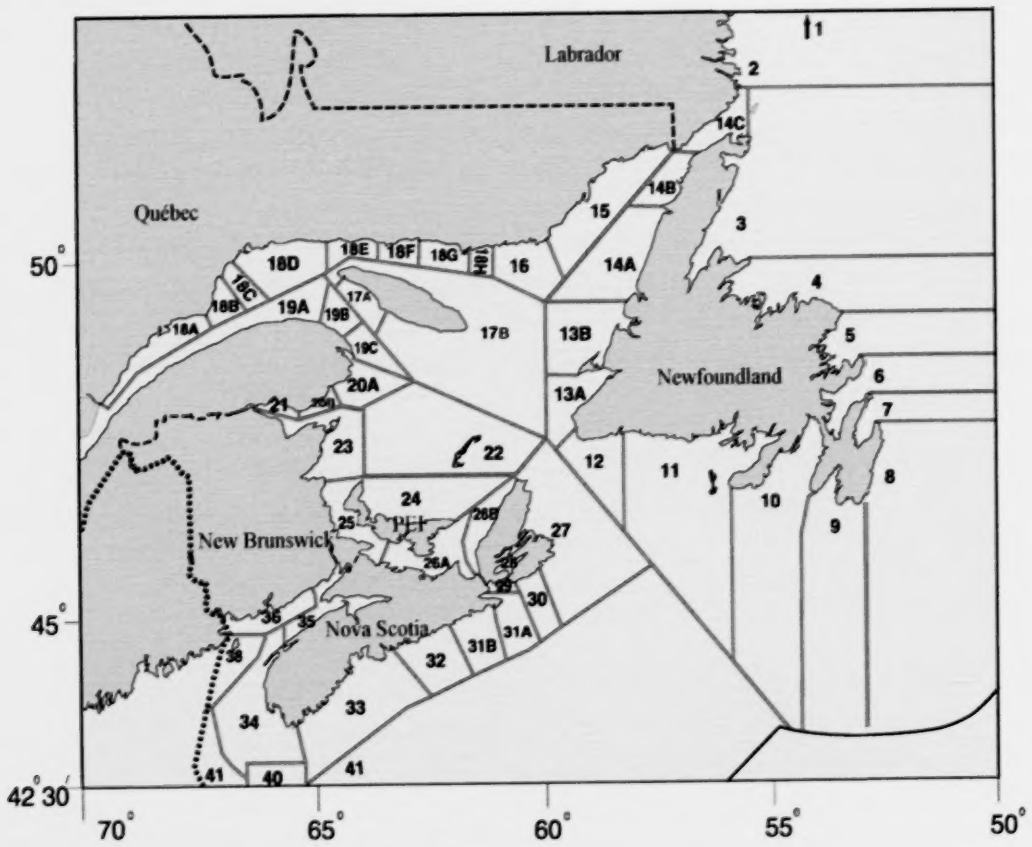

Figure 8. Lobster Fishing Areas in Atlantic Canada.

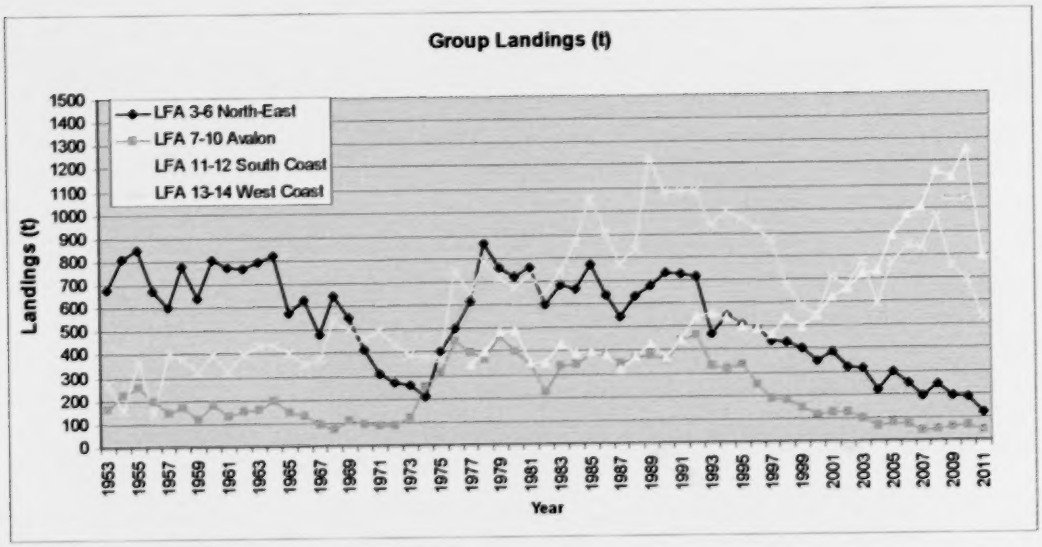

Figure 9. Lobster landings in the Newfoundland region.